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PID speed control of DC motor using meta-heuristic algorithms

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Article Info	ABSTRACT

This paper presents archimedes optimization algorithm (AOA) and dispersive flies optimization (DFO) to optimally tune gain parameters of PID control scheme in order to regulate DC motor's speed. These suggested techniques tune the controller by the minimization of the fitness function represented by the integral of time multiplied by absolute error (ITAE). The modelling and simulation are carried out in MATLAB/Simulink. The transient response of unit step input obtained from AOA-PID-ITAE and DFO-PID-ITAE controllers were compared to those obtained from Ziegler-Nichols (ZN) method and particle swarm optimization (PSO). The results indicate that AOA-PID-ITAE and DFO-PID-ITAE are more efficient than ZN method and PSO in reducing rise time and settling time. Likewise, DFO converge faster to the optimal solution with lower overshoot than AOA and PSO.

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1. INTRODUCTION

DC motors are actuators that produce angular rotation when supplied with electrical energy. They have significant importance in various electrical systems employed in domestic and industrial applications such as electrical vehicles, industrial mills and cranes, robots, and multiple home appliances [1], [2]. This importance is due to their advantageous characteristics like precision, convenience, and continuous control [3]. In order to drive the DC motor at appropriate speed or torque, it is necessary to have a proper control scheme.

PID controller is one of such control schemes employed in numerous industrial applications [4]. The term PID is an abbreviation for "proportional integral derivative" and a PID controller is a control system incorporating these three components. The integrator mitigates the controlled system's error, and the derivative provides improved output, adding to other advantageous reasons as to why PID controller has been preferred for more than eight decades [5]. The parameters of proportional, integrator and derivation gains, denoted respectively as K_p, K_i, K_d , are tuned to obtain desired output from the controlled process [6].

There are several classical approaches to tune the PID controller namely Ziegler-Nichols [7], Cohen-Coon [8], Chien-Hrones-Reswick [9], Astrom and Hagglund [10]. However, these conventional methods typically consume a great deal of time as tuning of parameters must be done iteratively until optimal solution is obtained [11] and results in undesirable overshoot [12]. To overcome these disadvantages, number of PID tuning methods have been proposed in the literature. One of such approaches is the usage of meta-heuristic techniques.

Metaheuristic optimization techniques are stochastic techniques that provides sufficiently acceptable solution(s) iterating the candidate solution(s) improving a certain metric, often referred to as the fitness value. Metaheuristic algorithms can effectively overcome the problem of getting stuck in local optima while exploration in the feasible solution domain and provide effective optimization in problems with complexities of time or dimensions [13], [14]. Control of DC motor has been a popular area where several meta-heuristic algorithms find application [15], [16].

In this paper, two metaheuristic algorithms are presented as tuning methods to tune parameters of speed-controlled DC motor, namely, archimedes optimization algorithm (AOA) and dispersive flies optimization (DFO). The paper is set in the following order: Section 2 outlines the methodology employed in the study with a brief description of meta-heuristic algorithms, Section 3 illustrates results and relevant discussions, and Section 4 concludes the study.

2. METHOD
2.1. Modelling of DC motor

An externally excited DC motor is employed in this study. The schematic of armature-controlled DC motor is illustrated in Figure 1. The voltage (E_a) is employed to regulate the angular velocity (ω) of the motor.
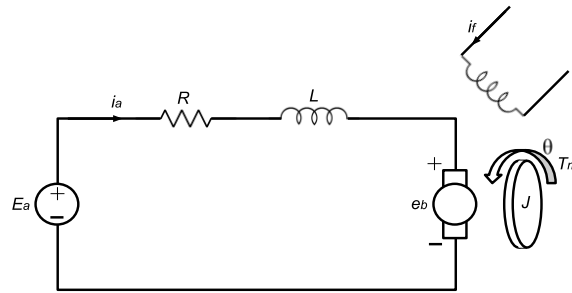

Figure 1. Schematic of armature-controlled DC motor

Rotating rotor interacts with the fixed field at right angle. So, the voltage induced across its terminal i.e, the motor back EMF (e_b) is proportional to the speed (ω)

$$e_b = K_b \frac{d\theta}{dt} \tag{1}$$

Where K_b is the back EMF constant. The governing mathematical model for armature loop is

$$E_a = L \frac{di_a}{dt} + Ri_a + e_b \tag{2}$$

Where i_a is the armature current, L is the inductance of armature winding, and R is the armature resistance. Since the torque established by the motor (T_m) is proportionate to current (i_a) in the armature

$$T_m = K_t i_a \tag{3}$$

Where K_t is the motor torque constant. The dynamic equation with coefficient of friction (f) and moment of inertia (J) is

$$T_m = J \frac{d^2\theta}{dt^2} + f \frac{d\theta}{dt} \tag{4}$$

Since, $\omega(s) = s\theta(s)$. The resulting transfer function for the speed-controlled DC motor is

$$G_M(s) = \frac{\omega(s)}{E_a(s)} = \frac{K_t}{(Ls+R)(Js+f)+K_bK_t} \tag{5}$$

For the model parameters considered, the resulting transfer function is.

$$G_M(s) = \frac{\omega(s)}{E_a(s)} = \frac{1}{0.222866s^2 + 0.77067s + 1} \tag{6}$$

2.2. PID controller

This study assumes to achieve a disturbance rejection controller by using a step input as reference. The controller efficacy is evaluated with regards to overshoot. rise time, peak time, and settling time of the closed-loop step response. The transfer function of the PID controller is

$$G_{PID}(s) = K_p + \frac{K_i}{s} + K_d s = K_p \left(1 + \frac{1}{T_i s} + T_d s\right) \tag{7}$$

where K_p, K_i and K_d represent proportional gain, integral gain, and derivative gain, respectively. Likewise, T_i and T_d represent the integral and derivative time constant. Also, $K_i = K_p/T_i$, and $K_d = K_p T_d$.

The schematic diagram of the proposed controller for speed control of DC motor is illustrated in Figure 2. Finally, for no-load condition with PID speed controller, the closed-loop transfer function is given by (8).

$$G_{closed-loop}(s) = \frac{\omega(s)}{\omega_{ref}(s)} = \frac{G_{PID}(s).G_M(s)}{1 + G_{PID}(s).G_M(s)} = \frac{K_d s^2 + K_p s + K_i}{0.222866s^3 + (0.77067 + K_d)s^2 + (1 + K_p)s + K_i} \tag{8}$$
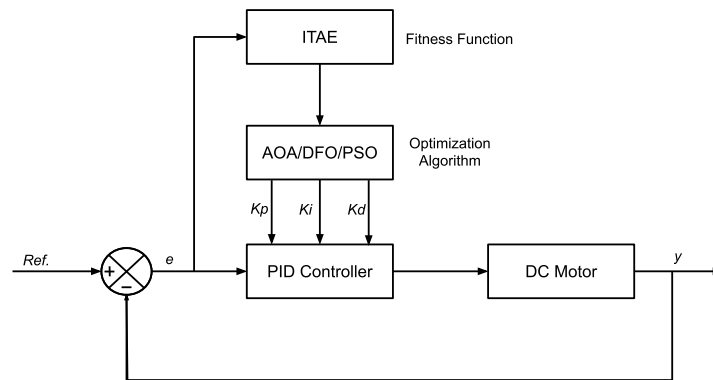

Figure 2. Block diagram of parameter optimization process of the PID controller

2.3. Ziegler-Nichols (ZN) method

The ZN method [17] to find K_p, T_i, and T_d is developed on the transient response of the system to be controlled. In this study, step response (open loop) method is employed. The open loop method involves locating the inflection point in the response curve where the slope of the response curve starts decreasing. The procedure is as, a) ensure that the response curve looks like an S-shaped curve as shown in Figure 3, for the open loop step response, b) draw a line tangent to the inflection point and measure the delay time (L) and time constant (T), c) measure the steady state gain of the plant (K), and d) finally, compute the controller parameters from Table 1.

Table 1. Ziegler-Nichols tuning formula [17]

Controller type	K_p	T_i	T_d
P	T/L		
PI	$0.9T/L$	$L/0.3$	
PID	$1.2T/L$	$2L$	$0.5L$

2.4. Meta-heuristic algorithms

2.4.1. Archimedes optimization algorithm

Archimedes optimization algorithm, in short AOA, is a physics-inspired metaheuristic technique proposed in 2020 [18]. It is based on the Archimedes' principle which states that for an object, submerged fully or partially in a fluid, buoyancy force acting on the object equates the displaced portion of the fluid's weight. In AOA, objects refer to the individuals of the population. The objects have physical properties like acceleration, volume, and density. AOA tries to converge to an optimum where these individuals are in equilibrium. In other words, resultant force acting on the object is zero and the object floats on the fluid. In initial stage of AOA, each object has random position in fluid. With iteration, AOA updates each object's density and volume. Iterations continue until termination criteria is met. The algorithm's implementation in optimization problem is illustrated by the pseudo-code.

```
procedure AOA
        Define population size N, maximum iterations T_max, constants C_1,C_2,C_3 and C_4
        Initialize population individuals with random positions, densities, and volumes
        Evaluate each individual's fitness and choose the optimum from these fitness value
        Set iteration counter T = 1
        while T ≤ T_max do
                for each object i do
                        Update density and volume
                        Update transfer and density decreasing factors TF and d respectively
                        if TF ≤ 0.5 then (Exploration Phase)
                                Update acceleration and normalize acceleration
                                Update position
                        else           (Exploitation Phase)
                                Update acceleration and normalize acceleration
                                Update direction flag F
                                Update position
                        end if
                end for
                Evaluate each object's fitness and select the best fitness
                Set T = T + 1
        end while
        return object with best fitness value
end procedure
```

2.4.2. Dispersive flies optimization

Dispersive flies optimization, introduced in 2014 [19], is inspired from two behaviours of flies: their swarming behaviour when they find a food source and their retreating and dispersing behaviour when encountered a threat. It has been employed in several discrete and continuous search spaces problems in the domain of medical imaging [20], training of deep neural network [21], optimization of machine learning algorithms [22]. DFO's implementation in optimization problem is illustrated by the pseudo-code.

```
while FE < 300,000 do
        for k = 1 → N do
                x⃗_k.fitness ← f(x⃗_k)
        end for
        sb ← {sb,∀f(x⃗_sb) = min(f(x⃗_1),f(x⃗_2),…,f(x⃗_N))}
        nb ← {nb,∀f(x⃗_nb) = min(f(x⃗_left),f(x⃗_right))}
        for i = 1 → N do
                for d = 1 → D do
                        τ_d ← x_{nb,d}^{t-1} + U(0,1) × (x_{sb,d}^{t-1} − x_{id}^{t-1})
                        if (r < dt) then
                                τ_d ← x_{min,d} + r(x_{max,d} − x_{min,d})
                        end if
                end for
                x⃗_k ← τ⃗
        end for
end while
```

2.4.3. Particle swarm optimization

Kennedy and Eberhart [23] suggested PSO which has its motivation in the collective behaviour of fauna which commute in groups. Each member in swarm is referred as a "particle" which moves around in the solution space. Their movements are governed by pre-defined rules. Each of these members, or particles, is assigned, a velocity value and a position value. The change in position is brought up by adjustment in velocity, which in turn depends on each member's best position and entire population's best position until

that instance. It has been employed in controller designing task for multiple times. Bayoumi and Soliman [24] employed PSO-based PI/PID controlling scheme for speed and current regulation of brushless DC (BLDC) motor. H. E. A. Ibrahim, F. N. Hassan, and A. O. Shomer [25] compared performance of PSO with bacterial foraging optimization (BFO) in regulating a BLDC motor's speed. R. V. Jain, M. V. Aware, and A. S. Junghare [26] tuned fractional order PID (FOPID) controller for similar application. The algorithm is represented in the pseudo code.

```
For member p
      Initialize member
End
Do
      For member p
            Evaluate the fitness
            If new fitness value optimal than personal best (pfbest)
                  pfbest ← new fitness value
      End
      Select the member with the best pfbest value as global best (gfbest)
      For member p
            Evaluate velocity using (1)
            Update position using (2)
      End
```

While stopping criteria not true
The update equations are as

$$V(k + 1, p) = W(p)V(k, p) + C_1 Rand[X(pfbest, p) - X(p)] + C_2 Rand[X(gfbest) - X(p)] \qquad (9)$$

$$X(k + 1, p) = X(k, p) + V(k + 1, p) \qquad (10)$$

Where k=iteration number, p=particle number, V=velocity, X=position, C_1, C_2=acceleration constants, $X(pfbest, p)$=personal best position of p_{th} particle, and $X(gfbest)$=global best position in population.

2.5. Performance index and response criteria

ITAE is a common performance index used in the design of a PID control. This index was selected to be our objective function because integral of square error and integral of absolute error, ISE and IAE respectively, weigh all error equally resulting in longer settling time. ITAE overcomes this limitation [27]. ITAE is evaluated using the (18).

$$ITAE = \int_o^T t \, |e(t)| d(t) \qquad (11)$$

Three response characteristics, particularly, the settling time, rise time and the overshoot of the plant introduced with the step input were observed. Then the response of the suggested algorithms, ZN method and PSO were compared. The data obtained are compared with that of PSO as it is the most used algorithm for synonymous task in literature.

2.6. Algorithm parameters

The simulations of transient response analyses of meta-heuristic algorithms are performed in MATLAB/Simulink environment. Results are obtained after 10 runs for each algorithm in laptop running 64-bit Windows 10, Intel(R) Core ™, i7-1067G7CPU @1.30GHz, 1.5 GHz, 8GB RAM. The initialization values used for the variables, kept fixed during each run of the code execution, of the metaheuristic algorithms are listed in the Tables 2.

Table 2. Initialization parameters for AOA, DFO, and PSO

AOA	DFO	PSO
Material numbers $= 50$	Population of flies $= 50$	Number of particles $= 50$
TF threshold for exploration phase ≤ 0.5	Delta $= 0.001$	Maximum iterations $= 100$
Maximum iterations $= 100$	Maximum iterations $= 100$	Inertial weight $(w) = 0.1$
$C_1 = 2$		Acceleration coefficient 1 $(C_1) = 1.2$
$C_2 = 6$		Acceleration coefficient 2 $(C_2) = 0.12$
$C_3 = 2$		
$C_4 = 1$		

The dimension of the problem to be optimized by the algorithms is three, referring to the three gain values of PID controller: Kp, Ki, Kd. The range of these gains used is.

$$0.01 \leq Kp, Ki, Kd \leq 20$$

3.   RESULTS AND DISCUSSION

To investigate the efficacy of AOA and DFO, their performance in transient response were compared with ZN and PSO. The chosen algorithms for performance comparison are AOA-PID-ITAE, DFO-PID-ITAE and PSO-PID-ITAE. Transient response criteria mainly include percentage overshoot (M_p), rise time (T_r), settling time (T_s), and peak time (T_p).

3.1.   Open loop response

Table 3 provides transient response criteria for the system when introduced with step input in the absence of controller. A mild overshoot of 1.1809% and settling time of 1.8354s is observed in the open loop step response suggesting the implementation of derivative action in the controller to mitigate the overshoot and reduce settling time. Also, the rise time of 1.1945s is observed in the open loop step response suggesting the incorporation of proportional and integrative action in the controller to reduce the rise time.

Table 3. Transient response criteria without PID controller

Transient response criteria	Values
$M_p(\%)$	1.1809
$T_r(s)$	1.1945
$T_s(s)$	1.8354
$T_p(s)$	2.5570

3.2.   Ziegler-Nichols method

As per the procedure described in Section 2.3., the parameters for computing the PID gains is obtained from Figure 3. The obtained parameters are $K = 1$, $L = 0.40476\ sec$, and $T = 0.64285\ sec$. The PID gain parameters computed using these values with the corresponding transient response criteria are incorporated in Table 4. The closed-loop response of the motor using PID gain parameters obtained from Ziegler-Nichols method has rise time of 0.7768s, settling time of 1.2518s, peak time of 5.1184s, and no overshoot. Hence, the Ziegler-Nichols method seems to have improved the system's transient response by removing the disturbance and reducing rise time and peak time. Although Ziegler-Nichols removed the disturbance form the transient response, peak time increased from 2.5570s to 5.1184s.
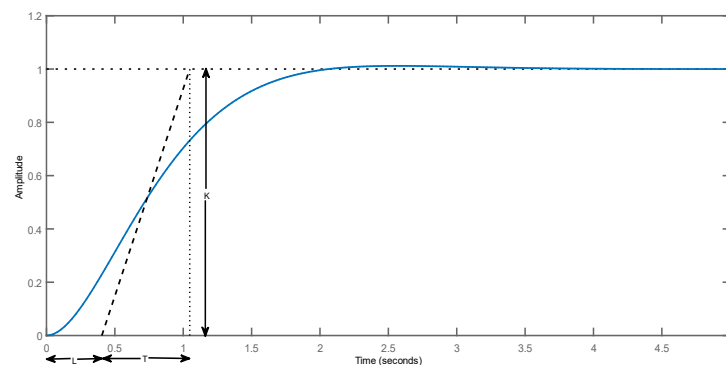

Figure 3. Funding K, L and T from 'S' shaped step response curve

3.3.   Meta-heuristic algorithms

Table 4 illustrates the best performance of the algorithms to produce optimal PID controller gains. The closed-loop response of the DC motor using PID gain parameters obtained from AOA-PID has rise time of 0.1100s, settling time of 0.1957s, peak time of 0.5516s, and 0.2600% overshoot. Hence, the AOA-PID

has improved the system's transient response by significantly reducing the peak time, the settling time, and the rise time. Similar conclusion can be derived for the transient response criteria of DFO-PID which has the rise time of $0.1098s$, settling time of $0.1951s$, peak time of $0.5349s$, and 0.4600% overshoot. These response criteria are better when compared to those obtained from ZN method and PSO-PID.

Table 4. Controller gains and transient response criteria

Controller type	K_p	K_i	K_d	$M_p(\%)$	$T_r(s)$	$T_s(s)$	$T_p(s)$
AOA-PID	15.4000	19.9704	4.4477	0.2600	0.1100	0.1957	0.5516
DFO-PID	15.4367	19.9997	4.4535	0.4600	0.1098	0.1951	0.5349
PSO-PID	13.6948	17.7389	3.9468	0.7700	0.1239	0.2198	0.5752
ZN-PID	1.9059	2.3543	0.3857	0.0000	0.7768	1.2518	5.1184

DFO-PID outperforms AOA-PID, ZN-PID, and PSO-PID in terms of rise time, peak time, and settling time. DFO-PID controller has rise time of $0.1098s$, settling time of $0.1951s$, and peak time of $0.5349s$. Likewise, AOA-PID ranks second with rise time of $0.1100s$, settling time of $0.1957s$, and peak time of $0.5516s$. With regards to overshoot, AOA-PID outperforms other meta-heuristic algorithms with 0.26% overshoot. Likewise, DFO-PID ranks second with 0.46% overshoot. Figure 4 shows the closed-loop step response of the system for all these controllers. Although all the meta-heuristic algorithms can reduce the disturbance in comparison to open loop response, small percentage of overshoot is still prevalent in the system. Figure 4 illustrates the closed-loop step response of the system for all these controllers.
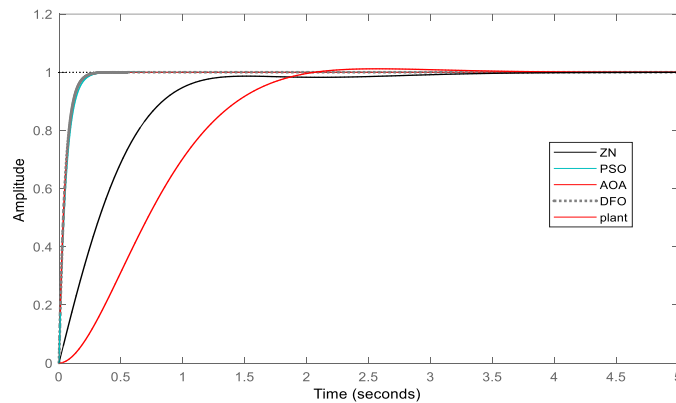

Figure 4. Closed-loop step response for all controllers

Table 5 provides the minimum value of the objective function these metaheuristic algorithms converge to after 100 iterations. This helps one conclude that the proposed tuning methods provide PID controller parameters with comparatively lower ITAE value which is a desired feature. DFO-PID controller, evidently, has the lowest ITAE with lowest standard deviation for 10 independent runs. Hence, the DFO-PID controller is the most accurate meta-heuristic algorithm based on ITAE fitness function. Likewise, DFO-PID is evident to show minimal variance in the result for different runs illustrating the high repeatability of the algorithm. AOA-PID ranks second after DFO-PID in terms of fitness function value as well.

Table 5. Best fitness function value for each controller

Controller type	Best fitness value (ITAE)	Standard deviation in ITAE
AOA-PID	0.002493	4.77E-04
DFO-PID	0.002484	2.3119E-06
PSO-PID	0.003153	9.22E-04

Figure 5 illustrates the convergence of the meta-heuristic algorithm for the best simulation run. It is observed that the suggested methods take less iteration to converge to provide an optimal PID controller. It is observable that the DFO-PID converges faster than AOA-PID and PSO-PID. While DFO-PID took only 18

iterations to converge to the ITAE of 0.002484, AOA-PID took about 50 iterations to achieve approximately the same. On the contrary, PSO-PID could only converge to ITAE of 0.003153 even with 100 iterations. AOA-PID and DFO-PID outperform ZN method and PSO-method in transient response criteria as well as in minimizing ITAE value. Furthermore, these two proposed methods take comparatively less iterations to converge to optimal ITAE value than PSO-PID.
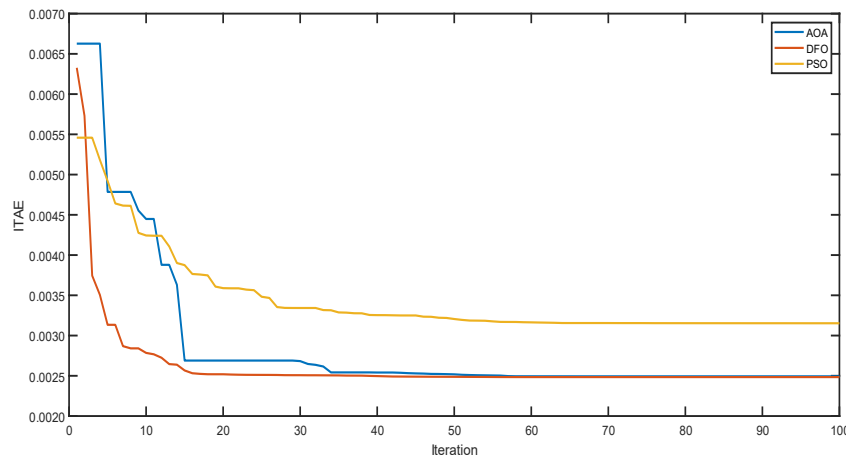

Figure 5. Convergence plot of meta-heuristic algorithms

4. CONCLUSION

In this study, two new approaches are presented to obtain optimum gain parameters of PID controller to regulate a DC motor's rotational speed. In controller design process, meta-heuristic algorithms are utilized to minimize the ITAE fitness function. Transient response characteristics of DC motor speed control system were employed to evaluate the efficacy of meta-heuristic algorithms. In this study, AOA, DFO, and PSO algorithms are considered for performance comparison. The numerical figures and graphical simulation results conclude that the proposed techniques outperform the classical ZN method and the popular PSO method. Hence, the proposed technique can be employed to ensure optimum performance of PID controller in large electrical systems, process industry and automation sector, among others.

REFERENCES

[1] W. Lan and Q. Zhou, "Speed control of DC motor using composite nonlinear feedback control," *In 2009 IEEE International Conference on Control and Automation*, Dec 2009, pp. 2160-2164.
[2] Q. V. Ngo, Y. Chai, and T. T. Nguyen, "The fuzzy-PID based-pitch angle controller for small-scale wind turbine," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 1, pp. 135-142, 2020, DOI: 10.11591/ijpeds.v11.i1.pp135-142.
[3] Dil Kumar T R and Mija S.J, "Design and performance evaluation of robust SMC schemes for speed control of DC motor," *In 2014 IEEE International Conference on Advanced Communications, Control and Computing Technologies*, pp. 88-92, DOI: 10.1109/ICACCCT.2014.7019235.
[4] R. Namba, T. Yamamoto, and M. Kaneda, "Robust PID controller and its application," *1997 IEEE International Conference on Systems, Man, and Cybernetics. Computational Cybernetics and Simulation*, Oct 1997, vol. 4, pp. 3636-3641, DOI: 10.1109/ICSMC.1997.633233.
[5] Š. Bucz and A. Kozáková, "Advanced methods of PID controller tuning for specified performance," *PID Control for Industrial Processes*, pp. 73-119, 2018, DOI: 10.5772/intechopen.76069.
[6] L. Chaib, A. Choucha, and S. Arif, "Optimal design and tuning of novel fractional order PID power system stabilizer using a new metaheuristic Bat algorithm," *Ain Shams Engineering Journal*, vol. 8, no. 2, pp. 113-125, 2017, DOI: 10.1016/j.asej.2015.08.003.
[7] N. Yadaiah and S. Malladi, "An optimized relation between T i and T d in Modified Ziegler Nichols PID controller tuning," *2013 IEEE International Conference on Control Applications (CCA)*, Aug 2013, pp. 1275-1280, DOI: 10.1109/CCA.2013.6662928.
[8] G. Cohen, "Theoretical consideration of retarded control," *Trans. Asme*, vol. 75, pp. 827-834, 1953.
[9] K. L. Chien, "On the automatic control of generalized passive systems," *Trans. Asme*, vol. 74, pp. 175-185,1972.
[10] K. Astrom and T. Hagglund, PID controllers: theory, design and tuning, 1977.
[11] M. N. Ab Malek and M. Ali, "Evolutionary tuning method for PID controller parameters of a cruise control system using metamodeling," *Modelling and Simulation in Engineering*, vol. 2009, pp. 1-8, DOI: 10.1155/2009/234529.

[12] G. M. de Almeida, V. V. R. e Silva, E. G. Nepomuceno, and R. Yokoyama, "Application of genetic programming for fine tuning PID controller parameters designed through Ziegler-Nichols technique," *International Conference on Natural Computation*, Aug 2005, pp. 313-322, DOI: 10.1007/11539902_37.

[13] M. A. Jusoh and M. Z. Daud, "Accurate battery model parameter identification using heuristic optimization," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 1, pp. 333, 2020, DOI: 10.11591/ijpeds.v11.i1.pp333-341.

[14] A. Memari, R. Ahmad, and A. R. A. Rahim, "Metaheuristic algorithms: guidelines for implementation," *Journal of Soft Computing and Decision Support Systems*, vol. 4, no. 6, pp. 1-6, 2017.

[15] S. J. Hammoodi, K. S. Flayyih, and A. R. Hamad, "Design and implementation speed control system of DC motor based on PID control and matlab simulink," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 1, pp. 127, 2020, DOI: 10.11591/ijpeds.v11.i1.pp127-134.

[16] S. Ekinci, D. Izci, and B. Hekimoğlu, "PID speed control of DC motor using Harris Hawks optimization algorithm," *2020 International Conference on Electrical, Communication, and Computer Engineering (ICECCE)*, Jun 2020, pp. 1-6, DOI: 10.1109/ICECCE49384.2020.9179308.

[17] J. G. Ziegler and N. B. Nichols, "Optimum settings for automatic controllers," *Trans. ASME*, vol. 64, no. 11, 1942.

[18] Fatma A. Hashim, Kashif Hussain, Essam H. Houssein, Mai S. Mabrouk and Walid Al-Atabany, "Archimedes optimization algorithm: a new metaheuristic algorithm for solving optimization problems," *Applied Intelligence*, vol. 51, no. 3, pp. 1-21, 2020, DOI: 10.1007/s10489-020-01893-z.

[19] M. M. Al-Rifaie, "Dispersive flies optimization," *2014 Federated Conference on Computer Science and Information Systems*, Sept 2014, pp. 529-538.

[20] M. M. al-Rifaie and A. Aber, "Dispersive flies optimisation and medical imaging," *Recent Advances in Computational Optimization*, pp. 183-203, 2016.

[21] O. M. Hooman, M. M. Al-Rifaie, and M. A. Nicolaou, "Deep neuroevolution: training deep neural networks for false alarm detection in intensive care units," *2018 26th European Signal Processing Conference (EUSIPCO)*, Sept 2018, pp. 1157-1161, DOI: 10.23919/EUSIPCO.2018.8552944.

[22] H. A. Alhakbani and M. M. al-Rifaie, "Optimising SVM to classify imbalanced data using dispersive flies optimization," *2017 Federated Conference on Computer Science and Information Systems (FedCSIS)*, Sept 2017, pp. 399-402, DOI: 10.15439/2017F91.

[23] J. Kennedy and R. Eberhart, "Particle swarm optimization," *Proceedings of ICNN'95-international conference on neural networks*, Nov 1995, vol. 4, pp. 1942-1948.

[24] E. H. Bayoumi and H. M. Soliman, "PID/PI tuning for minimal overshoot of permanent-magnet brushless DC motor drive using particle swarm optimization," *ELECTROMOTION-CLUJ NAPOCA*, vol. 14, no. 4, pp. 198-208, 2007.

[25] H. E. A. Ibrahim, F. N. Hassan, and A. O. Shomer, "Optimal PID control of a brushless DC motor using PSO and BF techniques," *Ain Shams Engineering Journal*, vol. 5, no. 2, pp. 391-398, 2014, DOI: 10.1016/j.asej.2013.09.013.

[26] R. V. Jain, M. V. Aware, and A. S. Junghare, "Tuning of fractional order PID controller using particle swarm optimization technique for DC motor speed control," *2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, Jul 2016, pp. 1-4.

[27] A. Idir, M. Kidouche, Y. Bensafia, K. Khettab, and S. A. Tadjer, "Speed control of DC motor using PID and FOPID controllers based on differential evolution and PSO," *International Journal of Intelligent Engineering and Systems*, vol. 11, no. 4, pp. 241-249.

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